Contract: W9132T-04-C-0021

Industrial Research Ltd

Midpoint Project Description Report

Proton Exchange Membrane (PEM) Fuel Cell Demonstration
Of Domestically Produced PEM Fuel Cells in Military Facilities

US Army Corps of Engineers
Engineer Research and Development Center
Construction Engineering Research Laboratory
Broad Agency Announcement CERL-BAA-FY03

US Antarctic Program Facility, International Antarctic Centre, Christchurch International Airport, Christchurch, New Zealand

June 2005

Executive Summary

This mid point report describes the installation of two 1kW fuel cells at the National Science Foundation (NSF) United States Antarctic Program (USAP) logistics base at the International Antarctic Centre in Christchurch, New Zealand. The day-to-day operation of this facility is contracted to Raytheon Polar Services, and the fuel cell project is managed by the offeror, Industrial Research Limited, a New Zealand Government owned research institute.

The proposed PEM fuel cell package consists of two Independence 1000 units manufactured by ReliOn Inc (formerly Avista Labs). The fuel cells are supplied by hydrogen produced on-site from two parallel methanol reformers, with a back up supply available from standard industrial compressed gas cylinders. The two GT-16 reformers are manufactured by Genesis Fueltech Inc. Conditioned fuel cell power at an installed peak capacity of 2kW is delivered at nominal 48Vdc battery bus voltage for a range of portable applications associated with a field base, eg, battery charging, instrumentation power, and field lighting. The system is used to provide year round night time yard lighting, and will be used for various other field energy supply applications during the day, such as charging of mobile equipment batteries and providing power for the system performance monitoring equipment and other building loads through a 2kW nominal grid connected inverter.

The system has a peak capacity of 2kW, with an availability target over the 12-month monitoring phase of 1kW due to the parallel redundancy provided by the two fuel cells. It is anticipated that the fuel cells will mostly be run in parallel with an average power output of around 1.2kW. If this anticipated average power output is maintained continuously for the 12-month monitoring period, then the total energy output of the system over that time will be approximately 10.5 MWh (megawatt hours). As local regulations only allow for a 100L methanol tank, this power level may be reduced over weekends and holidays to reduce the fuel refill frequency.

Every effort is made to run the system from methanol fuel, with the hydrogen backup only being used in the event that both reformers are out of service.

To simplify compliance with New Zealand safety regulations, the system is housed within a 10ft (half size) shipping container. This container provides an indoor environment for the fuel cells, reformers and monitoring equipment, whilst remaining separated from the existing building.

The host NSF facility in New Zealand operates a high profile international scientific program. This facility processes over 17500 researchers and other personnel per year, who will pass in close proximity to the demonstration site.

The host site contact information is:

Local:
Kerry Chuck kerry.chuck@iac.org.nz
Manager NZ Operations
Raytheon Polar Services (NZ) Limited
International Antarctic Centre
38 Orchard Rd
Christchurch
New Zealand
Phone +64 3 358 8139 Direct Dial: +64 3 358 8139 Mob: +64 27 226 5512
Fax +64 3 358 9060

USA:
Steve Dunbar Steve.Dunbar@usap.gov
Director of Science Support
Raytheon Polar Services Company
Phone 720 568 2019

Key subcontracts (value >US$5000) are ReliOn and Genesis Fueltech for supply of technology components.

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Proposal – Proton Exchange Membrane (PEM) Fuel Cell Demonstration of Domestically Produced Residential PEM Fuel Cells in Military Facilities

1.0 Descriptive Title

Demonstration of a 2 kW peak PEM fuel cell system for supplying field dc power at the US Antarctic Program Facility, International Antarctic Centre, Christchurch, New Zealand, fueled by integrated methanol reformers and back up compressed hydrogen cylinders. The system will operate at a minimum power availability of 1kW for at least 90% of a 12 month period.

2.0 Name, Address and Related Company Information

Offeror's Organization Name: Industrial Research Limited
Offeror's Organization Address: 5 Sheffield Crescent, PO Box 20028, Christchurch New Zealand
Offeror's Organization Phone Number (technical): +643 358 9189
Offeror's Organization Fax Number (technical): +643 358 9506
Offeror's Data Universal Numbering System (DUNS) Number: 590385274
Commercial and Government Entity (CAGE) Code: EO845
Taxpayer Identification Number (TIN), if known: -
Website: www.irl.cri.nz

Industrial Research Limited (IRL) is a New Zealand Government owned research institute. IRL is New Zealand's leading industrial scientific research company with international focus and reach. We provide scientific development, idea engineering and technology entrepreneurship to customers in New Zealand and around the world. We create and develop advanced technologies – or source leading edge technologies though our international networks. We also undertake technical consultancy activities in the advanced technology areas where we have demonstratable leading edge expertise, such as emerging distributed generation technologies. We have 400 staff based in New Zealand of which over 50% have PhD's - in Auckland, Wellington and Christchurch, and at our offshore offices in Australia, Singapore, Japan, the United States and the United Kingdom. We have an internal research program in fuel cell system development and other hydrogen technologies. For further information refer to our website www.irl.cri.nz.

3.0 Production Capability of the Manufacturer

The US supplier of the PEM fuel cell technology is:
ReliOn Inc
15913 E. Euclid Avenue
Spokane, WA 99216

Contacts:
Ken Hydzik, Western Region Manager, khydzik@relion-inc.com
Ph: 509 228 6500 Fax: 509 228 6510
Website www.relion-inc.com

ReliOn has provided two model Independence-1000 fuel cell units for parallel operation, with appropriate consumables and spares for the operating period of one year or longer as required. IRL engineers/technicians maintain the fuel cell generators at the demonstration site.

The unique design of ReliOn's modular cartridge technology is one that requires no specialized tooling or dedicated factories. Since the Independence product line consists of common materials and is made with existing manufacturing processes, ReliOn currently utilizes outsourced manufacturing contractors. Today, ReliOn has access to manufacturing capacity to fill orders of up to 50 units per week. In the event of a larger order, ReliOn would outsource to additional manufacturing entities.

The primary fuel is to be methanol. Two on-site methanol reformers, model GT-16 will be provided by US developer Genesis Fueltech Inc. with appropriate consumables and spares for the operating period of one year or longer as required. Genesis has opted to provide two GT-16 fuel processors instead of their smaller capacity GT-8 units. They have chosen to provide these higher capacity units at the same quoted cost. Each GT-16 reformer is capable of running either fuel cell at 80% load, or both fuel cells at a part load of up to 400W each. This provides redundancy as we can now ensure that both fuel cells can be run on methanol fuel, when one reformer is out for service. There appears to be an idle hydrogen consumption by the fuel cells of approximately 3LPM, or 20% of the full load consumption. Thus to delivery power within the rating of the fuel cell, it is much more efficient to run one fuel cell hard than two fuel cells at part power.

The US supplier of the reformer technology is:
Genesis FuelTech Inc
4922 E Union
Spokane WA 99212

Contact details for Genesis are:
Philip Piffer, CEO phillip@genesisfueltech.com
David DeVries, Technical contact, david@genisisfueltech.com
Ph 509 534 5787 Mobile 509 994 2132 Fax 509 534 5787
Website: www.genesisfueltech.com

These two core sub-systems were integrated at the offeror's site in Christchurch, and installed with monitoring instrumentation at the demonstration site by the offeror. The system is to be maintained and monitored for the duration of the project by the offeror.

4.0 Principal Investigator(s)

The offeror's principal investigators on the project will be:

Name: Ben McQueen (Project Leader) b.mcqueen@irl.cri.nz
Title: Research Engineer
Name: Alister Gardiner a.gardiner@irl.cri.nz
Title: Technology Platform Manager, Hydrogen and Distributed Energy
Name: Michael Callander m.callander@irl.cri.nz
Title: Fuel Cell Technology Manager
Company: Industrial Research Limited (Christchurch Site)
5 Sheffield Crescent, Christchurch, New Zealand
Phone: +643 3589189 Fax: +643 3589506

5.0 Authorized Negotiator(s)

Name: David Johnson d.johnson@irl.cri.nz
Title: Client Development Manager
Company: Industrial Research Limited (Gracefield Research Centre)
Gracefield Road, Lower Hutt, New Zealand
Phone: +644 569 0000 Fax: +644 566 6004

6.0 Past Relevant Performance Information

Industrial Research Limited initiated a systems integration activity in fuel cell technology over five years ago. The main focus of this work has been to evaluate and develop the technology for small scale distributed generation applications, both stand-alone and grid connected. Our strength in this area is primarily in the fuel cell stack balance of plant and the implementation of power electronics enabling technology to match the fuel cell output characteristics to a required power delivery standard.

Over this period of time, we have designed and evaluated the operation of a number of systems based on Zetek (E-Vision) stacks. These experimental systems have ranged from 0.4kW gross power output to 6.6 kW and this experience has allowed us to develop a core fuel cell generator unit. We are currently taking the engineering design of this system to a level suitable for batch production of field ready power supply modules for commercial evaluation in specific product areas, prior to larger volume implementation in commercial markets. Our first batch producible fuel cell generator, the 1.2kW output DCI-1200 is in the final testing stage and is beginning to attract interest from early market adopters and commercial clients.

We are currently research partners in the two New Zealand Government contracted hydrogen research programs, funded at approximately $US1m per annum. These programs are aimed at demonstrating New Zealand specific distributed generation scale technologies for:

- Coal to electricity via gasification and low temperature fuel cell generation
- Waste biomass to electricity via intermediate methanol fuel storage and fuel cell generation
- Renewable wind and solar PV electricity to hydrogen via advanced electrolysis for remote energy storage

IRL is providing the fuel clean up technology solutions, systems integtration, and fuel cell research and development resources in these programs, which are due to run for 2 to 6 years. Please refer to the IRL website for more information.

Industrial Research has just begun its own internally funded research program to research materials for hydrogen technologies. This four year program aims to develop at a fundamental level new materials for hydrogen manufacture, storage and utilization. This program will add valuable fundamental science support to our existing applications focused engineering development programs.

Our most recent demonstration level project was undertaken for the Australian Cooperative Research Centre for Renewable Energy (ACRE) in Perth, Western Australia. This system is a fully self-contained and stand-alone 6.6 kW alkaline fuel cell (AFC) remote area power system demonstration that is being used to study the electrolysis of wind energy to augment a bottled hydrogen fuel supply. Industrial Research Limited (IRL) has supplied the complete technical system to ACRE and is jointly conducting research in order to evaluate hydrogen storage and fuel cell technology combinations for remote area power supply. The system gained certification of compliance with New Zealand hazardous gases and electrical safety standards before shipping. ACRE Project 0180 was valued at US$684,000 of which US$171,000 was a direct cash contribution from ACRE.

Project contact details are:
Dr Trevor Pryor
Director, Murdoch University Energy Research Institute
Murdoch University, South Street
Murdoch WA 6150
Australia

Ph: 61 8 9360 6286   Fax: 61 8 9310 6094

7.0 Host Facility Information

The Host site is:

US Antarctic Program New Zealand Facility
National Science Foundation

Local Contact:
Kerry Chuck, Manager NZ Operations
Raytheon Polar Services (NZ) Limited
International Antarctic Centre
Christchurch
New Zealand
Phone +643 358 8139
Fax +643 358 9060
Email kerry.chuck@iac.org.nz

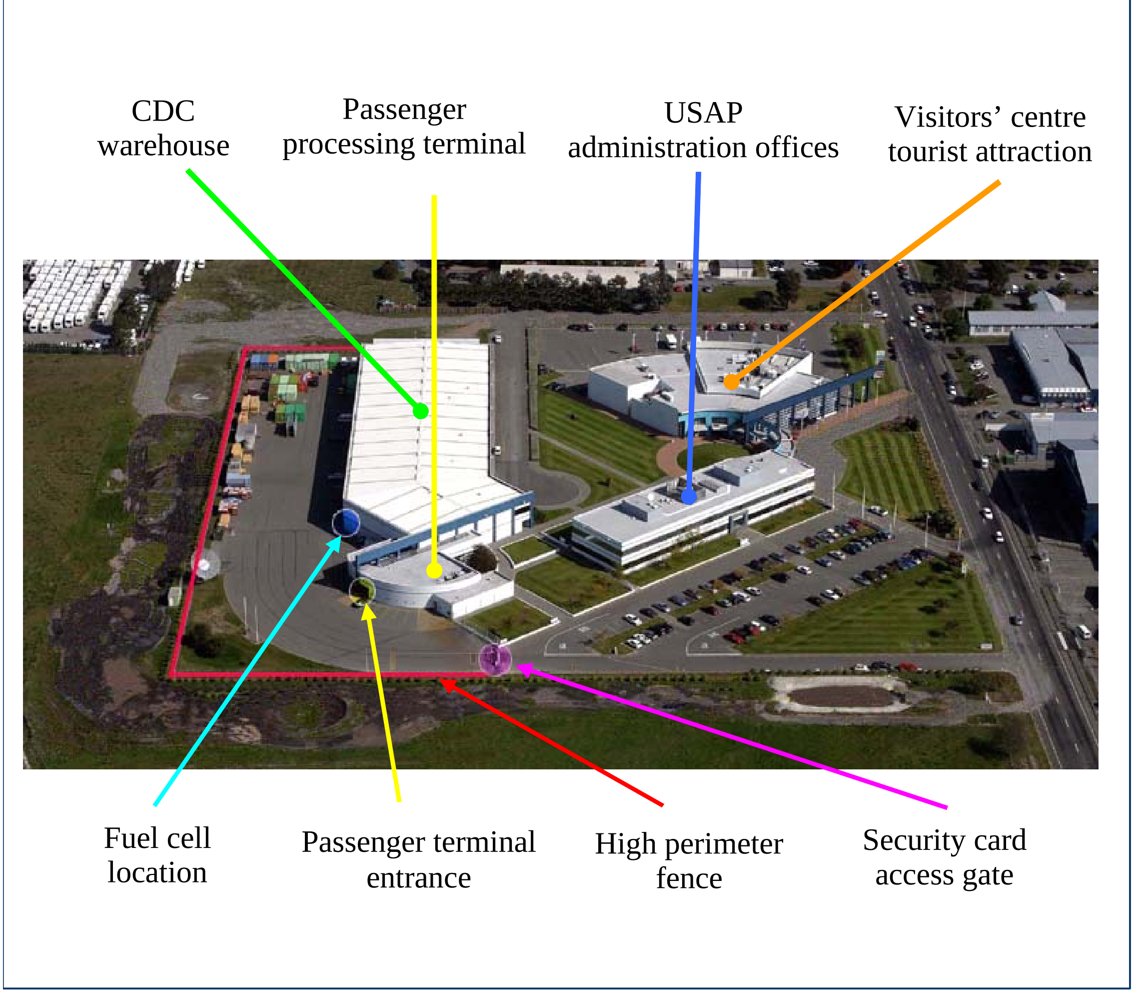
This host site is part of the International Antarctic Centre. This Centre is the logistics base for freight and personnel movements to Antarctica for programs run by several nations, including New Zealand and the United States. All personnel being flown to Antarctica pass through this facility and within a few metres of the proposed fuel cell installation location, with over 270 aircraft movements per year. The New York Air National Guard provides aircraft, logistics and support for USAP passenger and freight movements between Christchurch, Antarctica and the United States.

More specifically the fuel cell is installed in the yard adjacent to the United States Antarctic Program Clothing Warehouse. There are a number of functions performed from this building: a Travel Office where staff process travel and accommodation requirements, a clothing warehouse for storage of extreme cold weather clothing used by people deploying to Antarctica and a passenger terminal for processing people before they fly to Antarctica. The outside yard area is often used by New Zealand Customs and Aviation Security Service to exercise their explosive and drug detector dogs. The area is well fenced and access is only available by reader card.

The host has agreed to provide 24/7 swipe card access for key personnel for emergency maintenance and access to the fuel cell system, and daytime access for fuel deliveries.

The United States has used Christchurch as a logistics centre for their Antarctic Program since 1955 for both aircraft and ship movements. In 1964 the activities were taken over by the National Science Foundation (NSF) office of Polar Programs and the focus of operations shifted to the current site at Christchurch International Airport. The purpose built IAC facility was completed in 1991 and is currently used by the United States, the Italian Antarctic Program and Antarctica New Zealand. The building complex also contains the IAC Visitor's Centre, which is a major Christchurch tourist attraction with interactive displays, Antarctic vehicle rides and an Antarctic storm simulator.

An aerial view of the IAC complex is shown below, with key features marked.



The photographs on the next page shows a close up view of the 'fuel cell location' marked on the photograph above.

The site before installation at the kick off meeting in late 2004:

The containerized fuel cell room and hydrogen bottle cage arriving, Feb 2005: (Details of the interior fitout are discussed in section 8)

The fuel cell room installed in the CDC yard:

A view of the main security gate is shown below:

The IAC's electricity retailer is Meridian Energy with a physical connection to the Orion Networks distribution network. There is no liquid or gas fuel reticulated or delivered to the facility.

8.0 Fuel Cell Installation

Details of the installation location are described in the section above and shown in the digital photographs in the previous section. A site layout plan for the installation is attached as an appendix to this report. Man-hours and costs included in section 14.0 – Installation costs.

The PEM fuel cell package consists of two Independence 1000 units manufactured by ReliOn Inc (formerly Avista Labs). The fuel cells are supplied by hydrogen produced on-site from two parallel methanol reformers, with a back up supply available from standard industrial compressed gas cylinders. The two model 20L reformers are manufactured by Genesis Fueltech Inc.

Conditioned fuel cell power at an installed peak capacity of up to 2kW is delivered at nominal 48Vdc battery bus voltage.. The system is used to provide year round night time yard lighting, and providing power for the system performance monitoring equipment and other building loads through a grid connected inverter. The fuel cells provide conditioned power for the battery bus with a minimum total available capacity of 1kW, with a typical average power setpoint of 1.2kW when all equipment is operating. As local regulations only allow for a 100L methanol tank, this power level is reduced over weekends and holidays to reduce the fuel refill frequency, or if one reformer unit is out of service. Fuel consumption is typically in the order of 15 SLPM of hydrogen with the fuel cells operating at 1kW output. This requires 17cc/min of 65% (by vol) methanol blend. Thus for peak output approx 34cc/min of methanol is consumed, or around 20.5cc/min at the average power setpoint of 1.2kW. Thus approximately 11,000 litres of methanol will be required over the course of the 12 month monitoring period. Note that above figures suggest a minimal hydrogen consumption in idle, and fuel consumption may be higher if the base idle fuel consumption is higher than expected. Estimates at this point suggest approximately 3LPM is consumed when an I-1000 fuel cell is in idle. This represents approximately twenty percent of the full load fuel consumption.

On occasions when both reformer units are out of service for more than 24 hours for the purpose of unscheduled maintenance or repair, the fuel cells are operated in a UPS simulation mode instead of always-on mode. In this mode of operation, the fuel cells are switched on daily at 6pm and loaded at a level of approximately 1kW for a period ninety minutes. This simulates a typical outage that the ReliOn fuel cells are designed to provide backup power for, and tests their ability to reliably start up after a long period of inactivity.

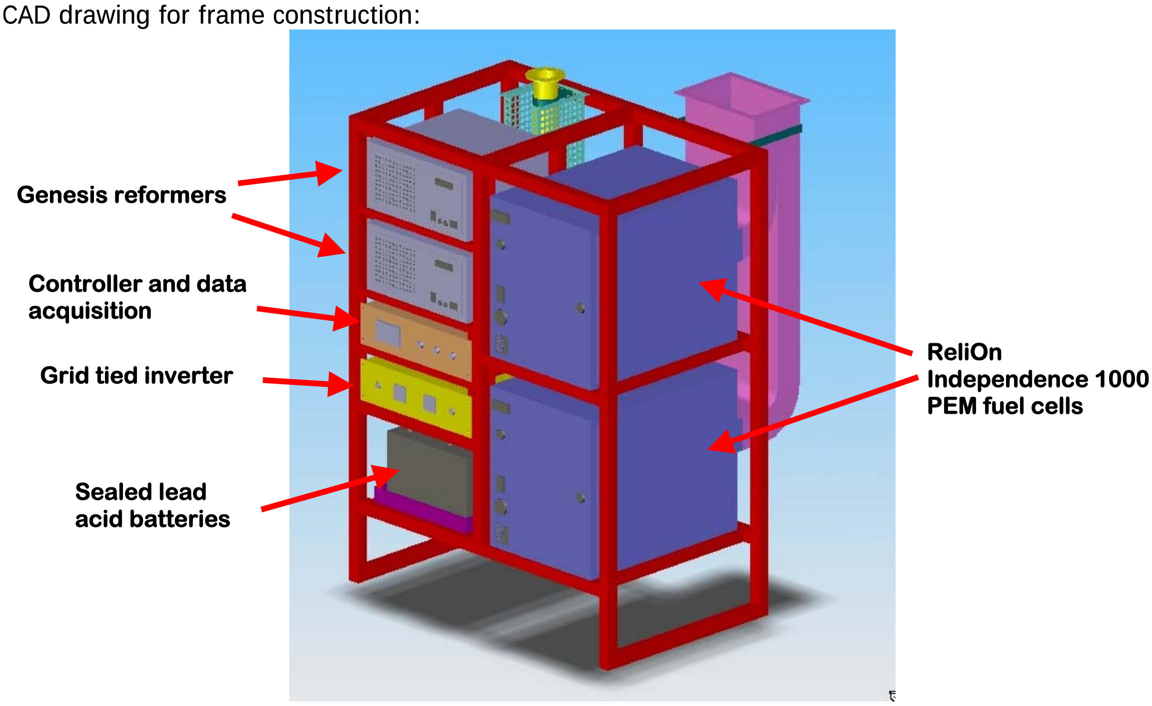
Running in this mode will offset the high cost of bottled hydrogen gas (compared to methanol fuel) as our budget does not allow for prolonged periods of running on bottle gas. Experience with the reformer units in our system testing phase has suggested that these outages may be for longer periods and more frequent than originally anticipated when the project was proposed and budgeted.

Before switching into this UPS operation mode, the technical POC at ERDC-CERL is notified of the reason for the outage and the expected date at which normal always on operation will be resumed.

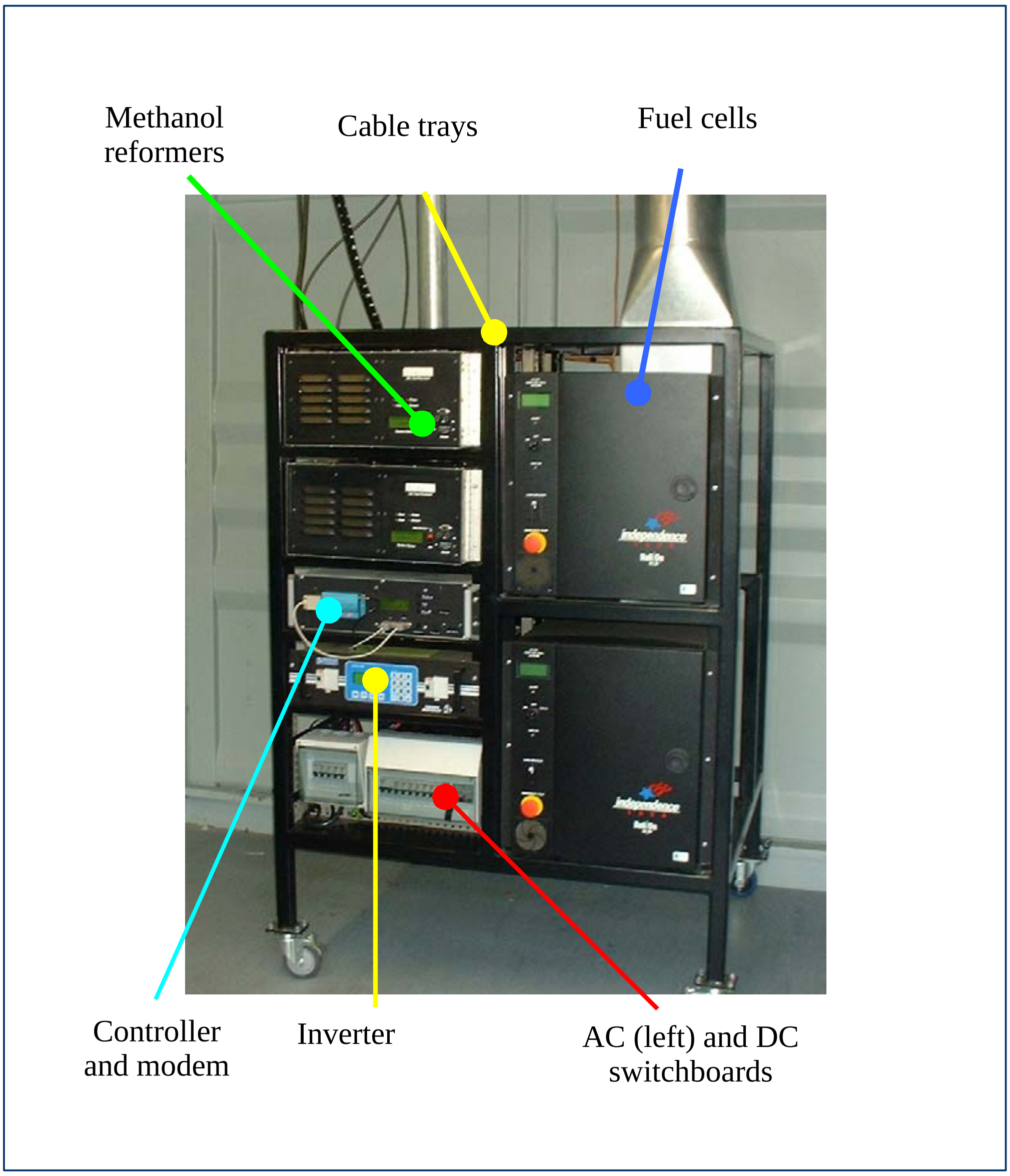
Note that the above fuel consumption data is based on information provided by our suppliers, ReliOn Inc and Genesis Fueltech. During the kick-off meeting, there was some discussion on the lifetime expectations for the ReliOn cartridges. As the ReliOn unit is designed as a UPS system, long term test have only been run for up to approximately 3000 hours. As these fuel cells will be run continuously there will be upwards of 9000 runtime hours accumulated. Should excessive cartridge failure occur then some renegotiation may be required, perhaps to consider running the system as a UPS simulation for a few hours each day. Our control unit is capable of being reprogrammed for this style of operation with little effort.

In the proposal it was indicated that the fuel cell system would operate as a semi-portable unit for field operation. With this in mind the full system including the two fuel cells, two reformers, control and data logging unit and the buffer batteries have been mounted on a steel frame designed for easy maneuverability on wheeled castors, with bearers for easy pickup by forklift. This unit of approximately 1mx1m footprint and 1.5m high is shown below.

CAD drawing for frame construction:



Finalised unit installed in containerized fuel cell room:

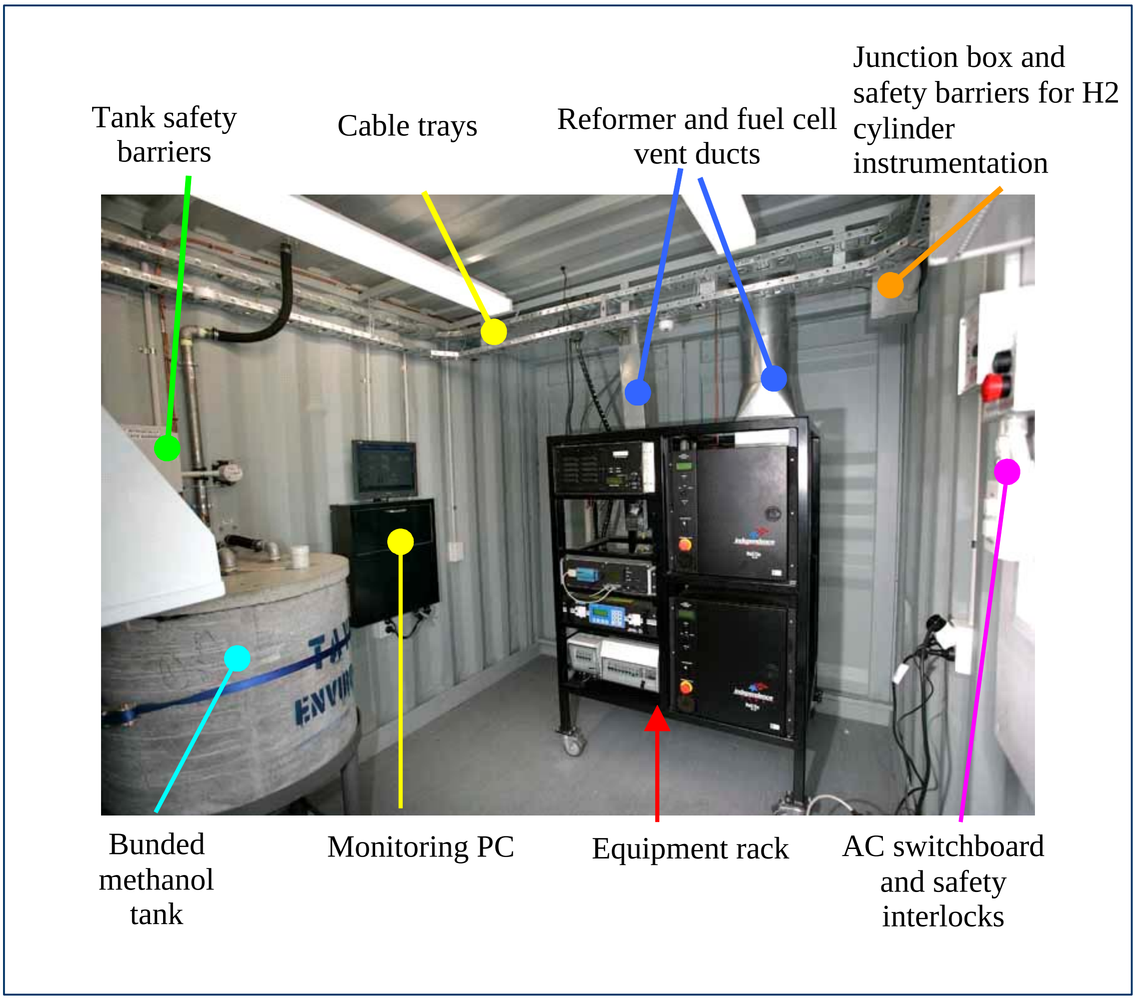


The fuel cells and reformers are designed for indoor use only, so this equipment rack must be either placed inside a building or environmentally sealed. Sealing the unit would prove unnecessarily cumbersome and expensive, and mounting the unit inside the building would require a large amount of space and construction work as local regulations would require a vented, fire rated room due to the use of flammable liquids and gases. Additionally the host would prefer that this experimental unit be kept outside their building as a fire caused by the fuel cell equipment could potentially damage the extreme cold weather garments that are issued to Antarctic personnel. Such an event could have serious impact on the Antarctic program.

With these constraints taken into account, it was decided to place the fuel cell equipment rack within a modified 10ft (half size) shipping container, as this provides a relatively compact outdoor enclosure at the most competitive price. AC lighting is installed within the container to allow 24/7 maintenance if required. Doors are placed in the ends of the container for personnel access, and large double doors at one end for equipment access.
Under local regulations, liquid and gas fuels must be stored at least three metres away from each other. Thus the hydrogen backup fuel tanks cannot be contained within or next to the container as this contains the methanol fuel mix. A tank farm of eight hydrogen ‘G’ cylinders ($6.3m^3$ each) are placed against the building wall a distance of three metres from the container housing.

Interior fitout of the container room are shown in the photographs below. Note the major components:

- Equipment rack with reformers, fuel cells, batteries, system control and a data acquisition
- PC for process monitoring
- Concrete bunded 100L methanol tank
- AC switchboard and safety systems



9.0 Electrical System

The fuel cell system is designed as an uninterrupted low voltage supply, to maintain a continuous 48V DC power output at a minimum of 1kW, peaking to 2kW with an average load throughout the test period of up to 1.2kW. This minimum 1kW supply capability is maintained by parallel redundancy through two 1kW ReliOn Independence 1000 fuel cells. Note that the power output or operation hours per day are reduced if one or more reformers are out for service.

The fuel cells provide a 54.2V output to a 48V battery bus. Thus the contracted availability can still be maintained with one fuel cell unit out for service. Running at 600W per fuel cell is the optimum efficiency point for the system, hence our target average energy supply rate of 1.2kW.

The fuel cell load is comprised of a nominally 1kW outside lighting load, which is used at night to supplement the existing yard lighting, and a grid-tied inverter to feed energy back into the grid during the daytime hours. Note that as the aim of this fuel cell system is to provide a stabilized 48Vdc battery bus supply for field applications, the use of the battery discharging inverter is simply because it is a convenient test load. While we meter the ac side output energy from the inverter for completeness, all reporting on power delivery, availability, and fuel efficiency is based on the energy delivered to the DC bus. The inverter can be controlled to simulate any load profile, however it will typically be used to draw approximately 1.2kW from the battery bank. The lighting load can also be turned on during daylight hours as a demonstration. In addition to these loads, a 50A battery bus output connector is available for connection of any portable low voltage DC equipment at the facility, and charging of sealed lead acid batteries (54.2V). The inverter grid feed is automatically reduced if the outside lighting is switched on.

The reformers draw a small amount of power from the DC bus for peripheral requirements.

Some AC power is used for control and instrumentation, enclosure lighting and safety systems. This is supplied via a single-phase 230V feeder from the host facility building, protected by an earth leakage breaker and isolator inside the building and a sub distribution board within the containerized fuel cell building.

While the fuel cells and reformers are capable of running from the battery powered DC system, the safety systems, system control and fuel delivery shutoff valves are powered by 230Vac. Thus, in the event of an AC power loss, the system will shut down due to the tripping of the safety systems and requires manual restart intervention.

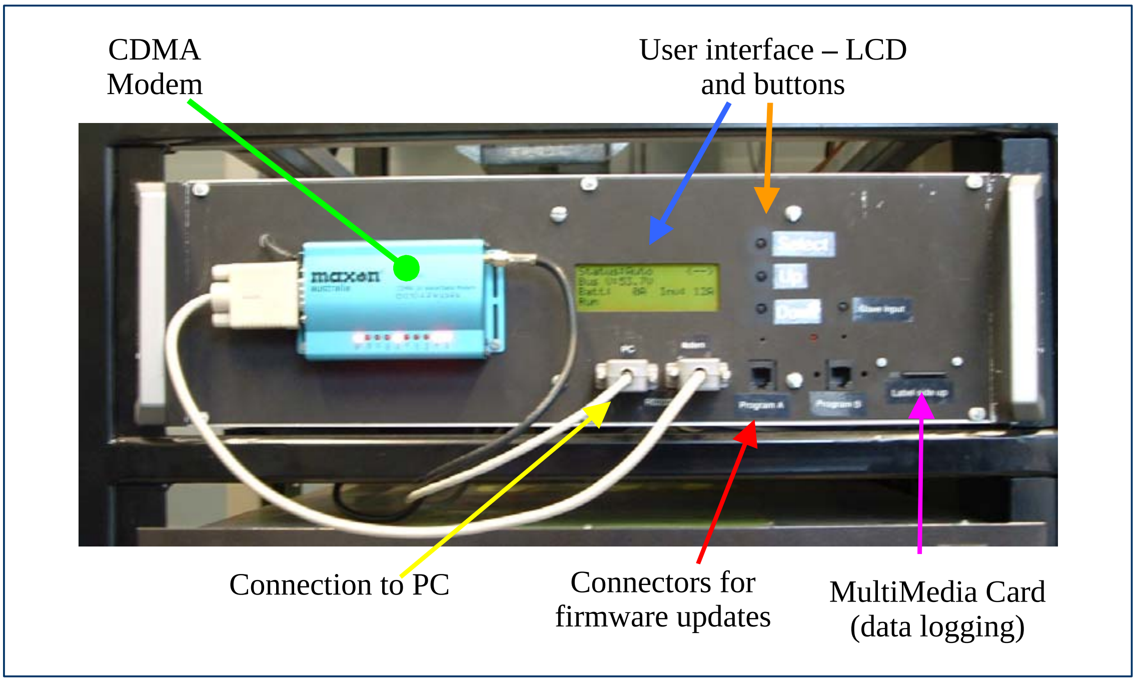
10.0 Thermal Recovery System

Not applicable. (There is no thermal recovery system associated with this project).

11.0 Data Acquisition System

The system uses a control and data acquisition system developed in-house for control and monitoring of our distributed generation and fuel cell products. This system has been developed over the last two years and is in constant use at two distributed generation field test sites and on three alkaline fuel cell products. The use of this platform provides us with flexibility to quickly customize a data acquisition system to our specific needs. It also allows fast turn around for servicing and repairs, as in the New Zealand market even 'off-the-shelf' replacement parts for

standard data logging systems can take one week or more to arrive – a time frame that is unacceptable for this project.
This control data acquisition system is housed in a 3U sized 19" rack mount case with over thirty inputs for standard industrial sensors, and twenty-six 24Vdc power output contacts. Data is logged to a MMC flash memory card in Excel spreadsheet format, which can then be directly read on a Windows PC.



The following parameters are to be monitored and logged:

- Fuel cell module output currents
- Battery bus voltage
- Fuel gas delivery pressure
- Methanol fuel tank level
- Hydrogen backup tank fuel pressure
- Ambient temperature (outside)
- Temperature inside experiment enclosure
- Reformer operation status outputs
- Fuel cell operation status outputs
- Methanol refill times and amount
- Backup hydrogen tank changeover times and residual (empty) pressure

From these monitored parameters listed above, the following additional quantities are inferred:

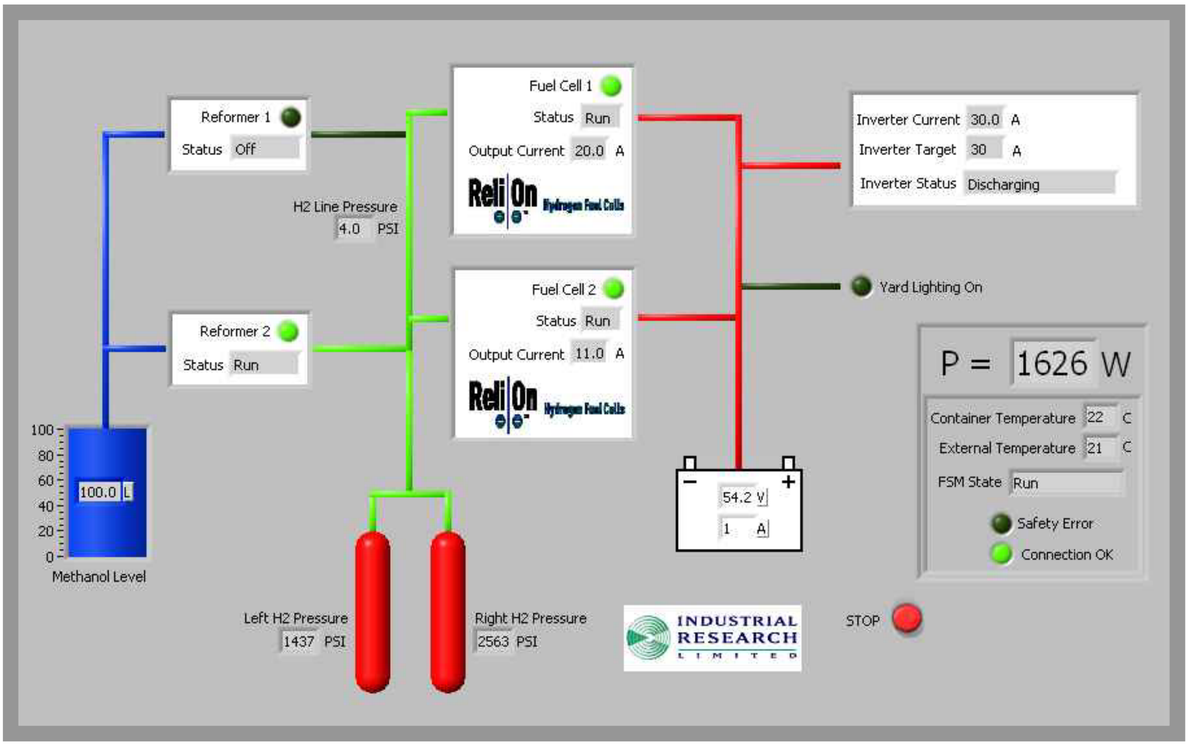
- Gross system output power and totalized energy
- Individual fuel cell power output
- Fuel cell energy production
- Reformer methanol mix fuel consumption
- Backup hydrogen fuel consumption
- Fuel cell and reformer operation and outage times and durations
- Fuel source – methanol or hydrogen

Through a set of relay and MOSFET outputs, the data acquisition and control system is capable of starting and stopping both fuel cells and both reformers, the inverter, yard lighting and all other peripheral systems. All items can be forced on or off, or left to be automatically controlled by the system controller. The system controller is programmed with ‘profiles’ to allow continuous adjustment of the load throughout the week by switching on and off the yard lighting, and adjusting the inverter setpoint.

Our typical logging procedure is to log data every one minutes and also immediately following any abnormal event. This will typically result in around 8MB of data per month. Data cards will be changed on approximately a weekly basis and copied onto Industrial Research’s computer network, which has normal RAID and tape backup systems. A typical data log is attached to this report. Our engineers have written macros to compile these weekly data logs into monthly lots for reporting purposes. Similarly, macros analyze this monthly compiled log to provide the information for our summary data that is provided in the monthy Data Reports.

In addition to this data acquisition system, there is a PC provided in the containerized room for process monitoring and demonstration purposes. Note that this PC screen is for information purposes only – all decision making and data logging is done by the embedded system.

A screen shot of the PC system is shown below:



In order to help meet the 90% availability target and for safety monitoring, we have installed a cellular phone based SMS paging system. In an abnormal condition, the system will send a text message to the on call engineer with the system status. Such events can include low methanol or hydrogen levels (indicating that a refill is needed) minor alarms in the reformers or fuel cells, low fuel pressures or voltages or failure of a critical safety system.

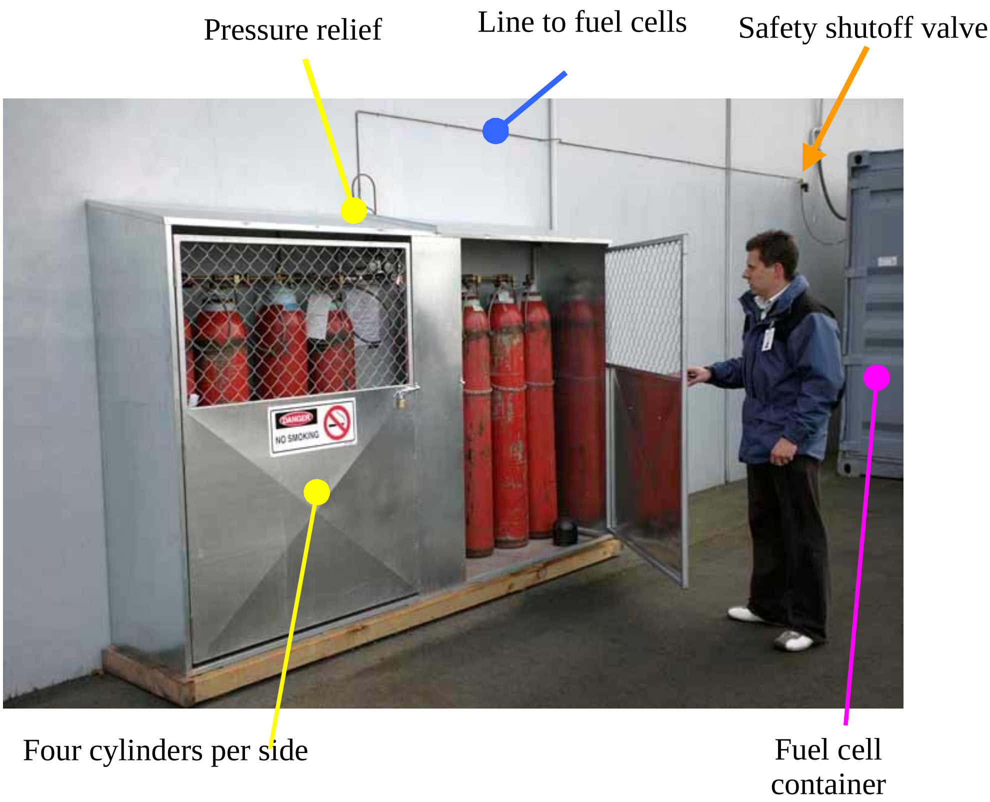
The engineer can then respond appropriately if required. In addition, this SMS system allows engineers to modify the control parameters and setpoints, turn on or off the fuel cells or reformers and check on fuel levels. All these features are of course password protected to ensure that only authorized users can interrogate or adjust the system.

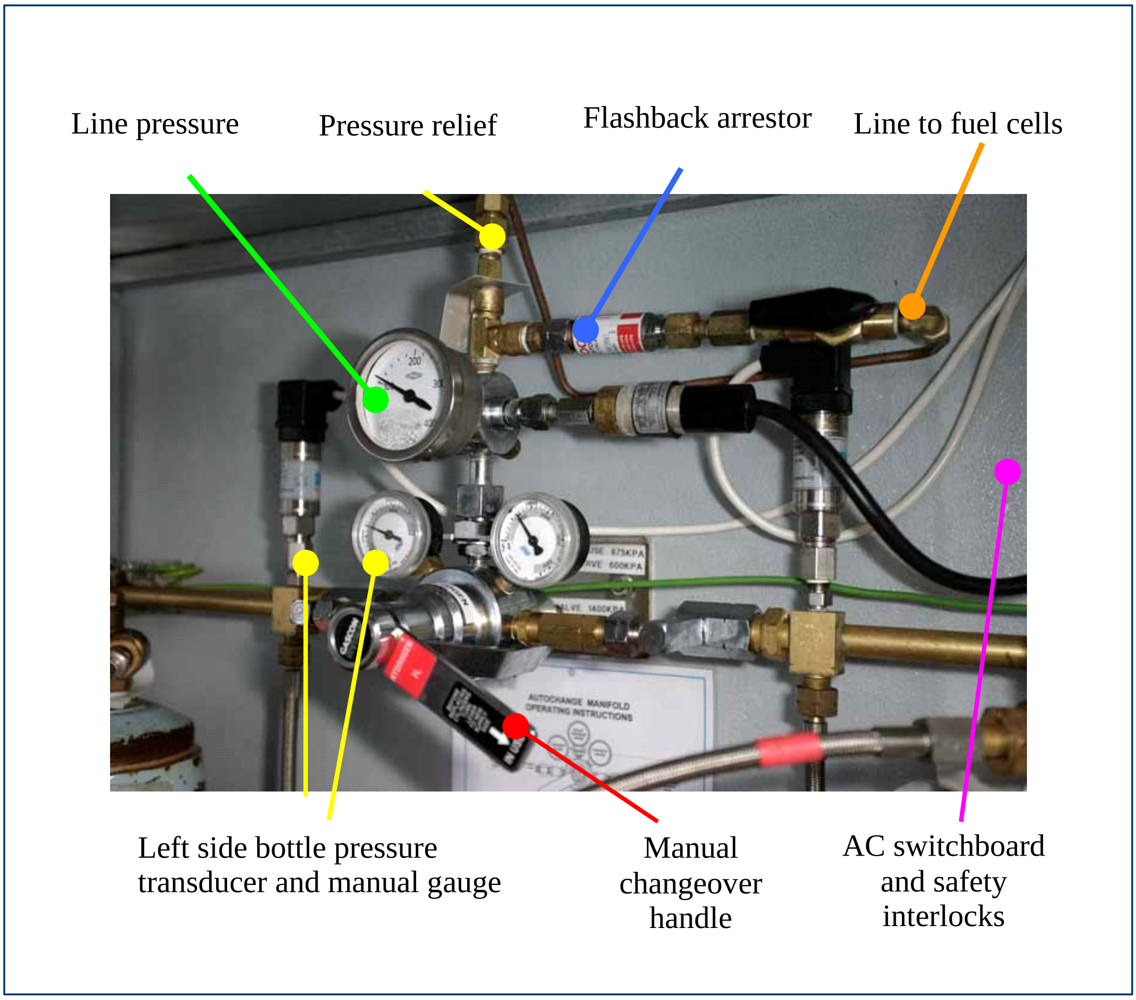
12.0 Fuel Supply System

This is a dual fuel system, capable of operating either through a methanol fuel blend or hydrogen gas.

Hydrogen fuel delivery:
Hydrogen gas is provided from a four per side auto changeover manifold system manufactured by Gascon Systems Pty Ltd. This provides a total of eight $6.3m^3$ gas cylinders for a total capacity of $50.4m^3$.

The gas bottles are housed within a cage attached to the side of the CDC building, as shown in the photo below:





This manifold system automatically changes from one bank of four cylinders to the other when the 'in use' side pressure reduces to less than 100psi (approx 4% left in the bottles, which are pressurized to 2200psi when delivered.) A contacts signal is sent to the system controller when this change is made to advise that one side of the manifold system is empty and requires a changeover. Hydrogen gas is sourced from BOC gas and delivered to the site by a BOC delivery truck as required. When running from hydrogen in UPS mode, this is approximately one four cylinder delivery every twenty days. If running in always on mode from reformer, the deliveries are obviously less frequent and predictable as the hydrogen usage reduces to zero, except if there is a reformer fault.

The line delivery pressure is set via a fixed pressure regulator to 30psi, with a pressure relief at 32psi.

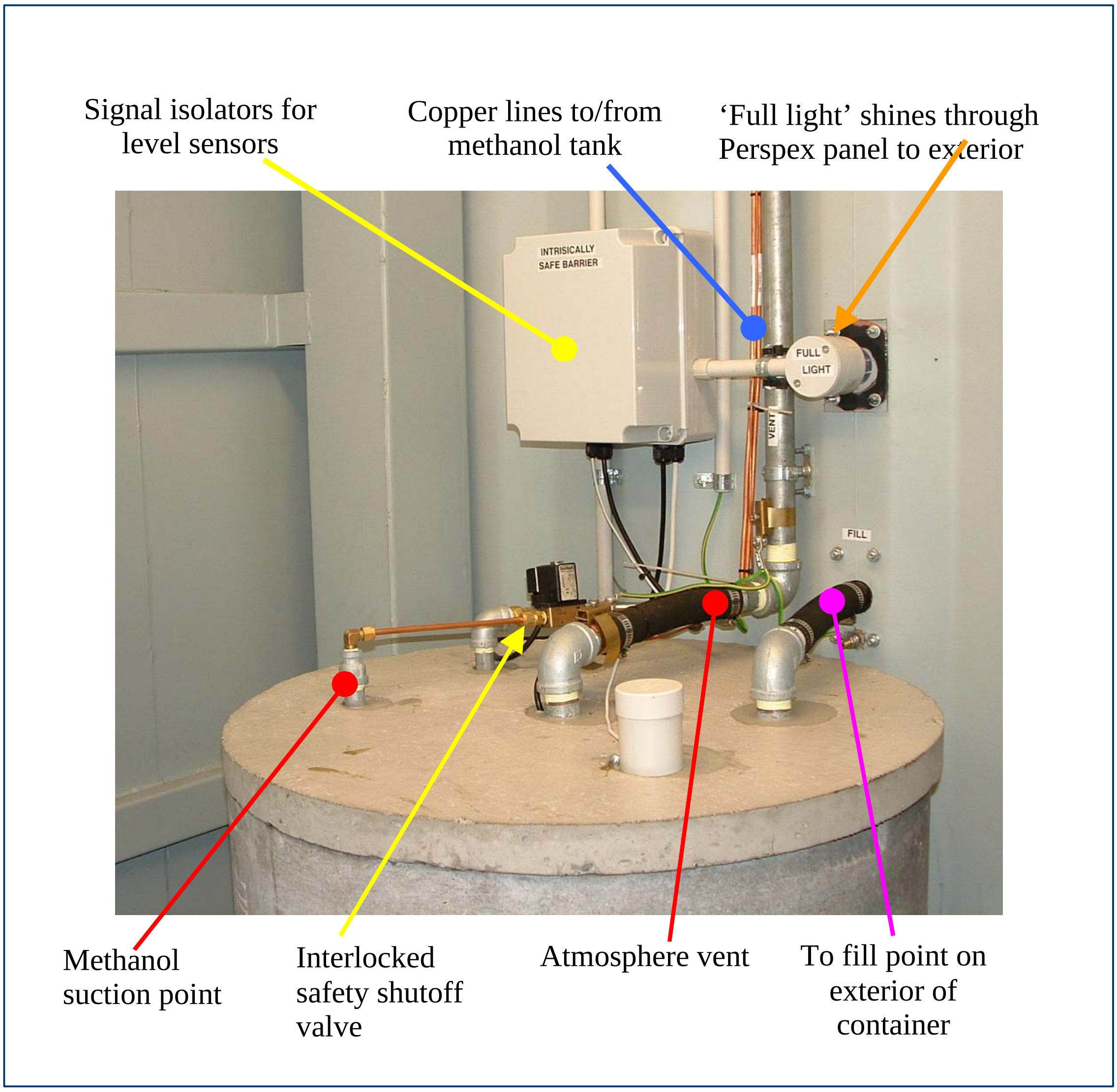
In addition to the changeover switch, there is also a 4-20mA pressure sensor on each side of the changeover manifold to measure the pressure on each side of the bottle bank in psig. Initially all these sensors were directly connected to the data acquisition system, however when inspected for electrical safety we were advised that because our bottle cage contained more than 30m^3 of flammable gas, the interior of the cage was considered a Zone 1 hazardous environment under safety standard AS/NZS 2430.34:2004. This means that the sensors had to pass through low energy isolating signal repeaters, or be Ex rated. As a cost of over $1000 and delay of two weeks we opted to install the signal repeaters.

Methanol fuel delivery:
Methanol fuel is a class 3.1B Flammble liquid under the Hazardous Substances and New Organisms (HSNO) Act, and the following limits apply:

1. If more than 250 litres of methanol fuel is to be stored or transported, an approved storage area must be used and an approved, trained handler must be present.
2. If more than 100L of methanol is stored in a closed container then a hazardous atmosphere must be observed around the container/tank.

With appropriate spun concrete bunding around a 250L tank we could have argued that from a pragmatic viewpoint that this provided a hazardous atmosphere barrier. However in order to reduce complexity, we opted to keep the tank size below the 100L limit, thus it became a completely 'non-hazardous' fuel store. With the addition of a spun concrete bund there is also secondary containment in the event of a fire, and protection against the ecotoxic nature of methanol.

The tank is constructed from mild steel, and final manufactured volume was actually 90.2L. The suction tubes do not drop completely to the bottom of the tank, and there is a residual 12L that cannot be utilized. Thus the total working range is 78L. Beneath the tank inside the concrete bund we have placed a pressure sensor which is used to measure the volume of liquid in the tank due to the known fuel density and tank surface area.



This 100L tank is refilled twice per week from a 200L drum which an Industrial Research engineer or technician takes to the site on a trailer. This is another clear example of how transport fuels and applications have much more relaxed laws and requirements than fixed installations. The irony is not lost on us that it is more acceptable to tow a trailer with 200L of methanol behind a car at high speed than have a stationary 100L tank.

We store up to twenty 200L drums in our certified dangerous goods store at the Industrial Research Ltd facility. These drums are bulk delivered in batches of sixteen as required.

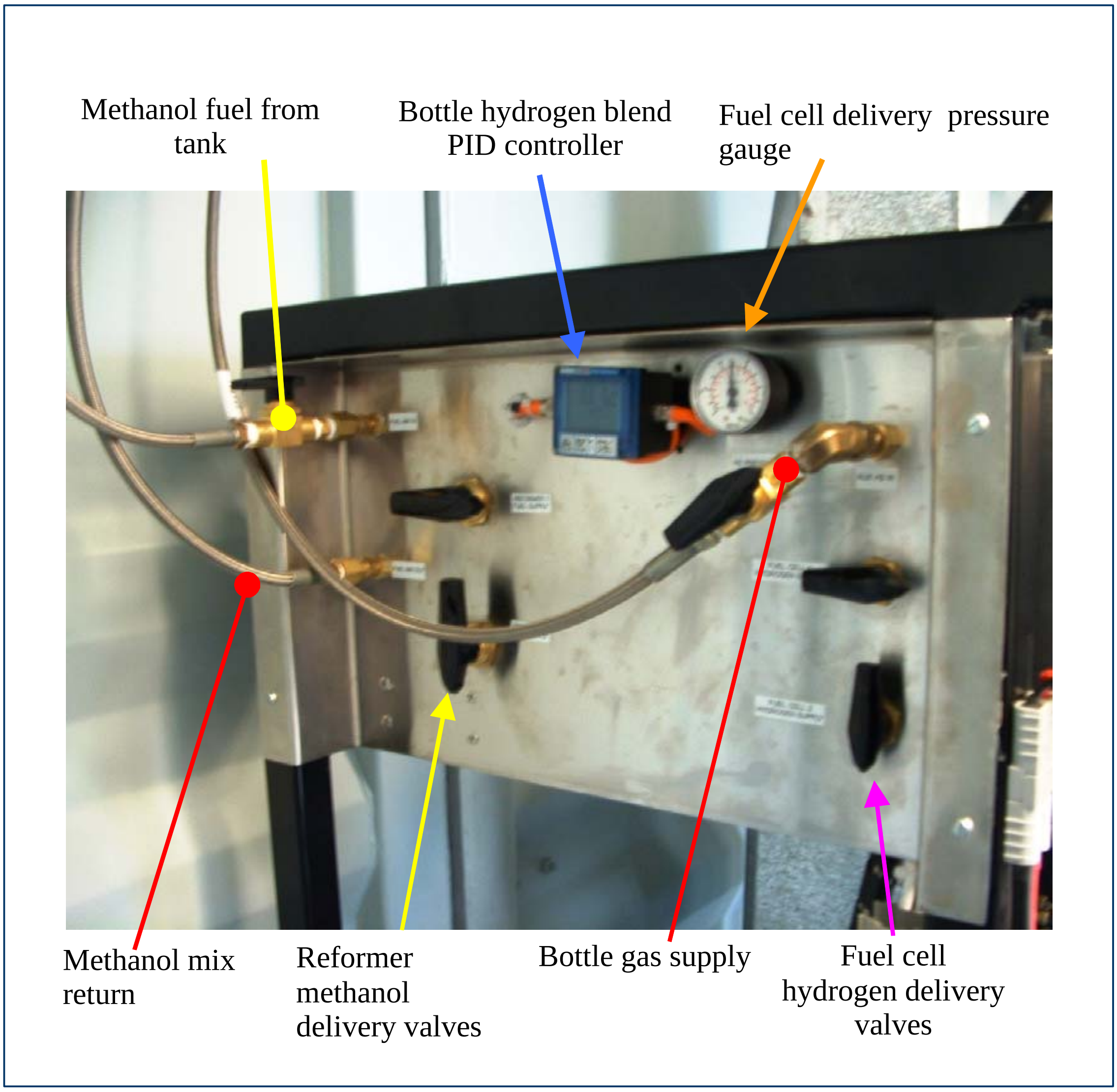
The methanol fuel is a 64/36 v/v% mixture of methanol and water. The feed stocks are supplied, blended and delivered to Industrial Research Ltd by Australasian Solvents and Chemicals Company.

Fuel is suctioned directly from the 100L tank by the reformers through a ¼" copper line which rises to the roof of the container then down to the reformers, a total run length of nearly three metres. Care was taken when designing the tank stand and plumbing that the top of the tank was lower than all pipework and plumbing, such that in the event of a pipe breach there could be no siphon effect causing an uncontrolled methanol spill. As per normal liquid fuel deliver principles there is a mix return pipe also to provide a return path when priming the reformers and fuel lines.

It was found during the first month of operation that after operation for about two and a half to three days the reformers would stop running - reporting a lack of fuel - despite the fuel tank having sufficient fuel remaining. Through discussion with the reformer manufacturer it was determined that the most likely cause of this was probably due air bubbles forming in the fuel lines. It was known from product testing in the Genesis lab with clear urethane lines that bubbles form in the tube due to entrained air in the mixture separating out when the fluid was under suction. In the short tube run, these bubbles were generally sucked through with the fluid flow into the reformers and caused little problem as the reformer just pumped a little harder if a small bubble was encountered. In this installation the three metre pipe run with a long horizontal section, these bubbles caused a problem over time as they were getting stuck in the pipe due to surface tension with the relatively slow fuel flow bypassing the stuck bubbles (the fuel flow is less than 20cc per minute). Over time the small bubbles joined together as one large bubble which was then eventually sucked towards the reformers causing them to shut down due to lack of fuel as the reformer could not pump air fast enough to prime the line again before the residual fuel in the system was reacted.

This problem could be solved in two ways. The first – reduce the size of the fuel delivery pipe to 1/8" so that the smaller diameter tube would force the bubbles to be dragged along with the fluid flow. This was tried but it was very difficult to prime such a long length of small diameter tube. A second option was taken early in the second month of operation by adding a circulating pump to existing fuel delivery lines. This circulating pump is operated on a one minute in ten duty cycle and causes the fuel to be pumped at higher speed around the fuel delivery lines stopping bubbles from forming. It has now been operating for over a month and has solved the problem.

Final delivery manifolding:
The final hydrogen fuel delivery to the fuel cell passes through a manifold panel such that hydrogen can be delivered to either or both fuel cells from either of the two reformers, the bottle gas supply or a combination of two or three of these sources. The manifold panel is shown below:



Behind the panel (not shown) is a modulating valve for bottle gas blending (controlled by the PID controller in the photograph), and a pressure transducer for data logging and closed loop control.

13.0 Safety Systems

Both fuel cells and fuel processors manage their own emergency shutdown procedures in the event of an internal fault. Should one fuel cell shut down, the other's output will increase to compensate and still maintain supply to the load. Similarly, should one reformer fail, the other will be switched in to maintain hydrogen supply. Should both reformers fail, and while reformers are changing over, the auxiliary hydrogen supply will be switched in so the fuel cells stay running.

In the event of a critical safety failure, the fuel supplies are immediately cut off through hard-wired safety interlocks, thus protecting the system to our local safety standards. A critical safety failure is defined as any of:

- Flammable gas content in the experiment room exceeding 25% of the lower explosion limit. For hydrogen gas, which has an LEL of 4% v/v, this means 1% hydrogen in the air.
- Failure of the fume extraction system

- Rise of the ambient temperature in the room above 55 deg C
- Manual actuation of an emergency fuel stop button (of which there are two – one inside, the other outside the container)
- Loss of AC mains network power

Any of these conditions will cause a solenoid valve to close on both the suction outlet of the methanol tank and in the hydrogen gas supply line, shutting off all fuel supply to the process.

The experiment room is force ventilated in accordance with our local safety standards, AS/NZS2430 and AS1482. This ventilation is designed such that in the event of the worst possible conceivable methanol or hydrogen leak, the concentration of explosive gases in the room is kept below 25% of the lower explosion limit (our local safety limit) due to the 200L/sec fresh air exchange. The 'worst case hydrogen leak' is where there is a breach of one of the copper pipes in the room. In this case the gas leakage is known to be within a defined maximum due to the fixed gas pressure regulation at the manifolding and known valve orifice size – hence the maximum flow rate is known based on the pressure differential and orifice size.

There is no automated re-close - the safety systems must be restarted with human intervention by pressing a manual 'start' button.

14.0 Installation Costs

We decided early in the project to perform the installation as a showcase demonstration of the technology and our capabilities. Thus, the installation may be somewhat more elaborate than other Residential PEM installation contracts that have been awarded. This has increased the cost of some of the components, particularly the container fitout and labour time by our engineers. Costs such as exterior signage, linoleum flooring (to name two examples) could have been avoided if we wanted to install a cost minimized system.

There were more issues than anticipated in the integration of the reformers. The reformers were more experimental than we had initially believed which resulted in several issues that needed to be addressed through correspondence prior to delivery and engineer's time on the three visits that Genesis engineers have made the Christchurch.

Additionally, for our own piece of mind, and also at the wishes of the hosts, we have taken a very conservative approach to the interpretation of safety standards and regulations. This means that some other costs (such as a bunded fuel tank, or intrinsic safety barriers) are also additional to strict requirements.

Note that most of the parts listed below are purchases made in New Zealand, in New Zealand dollars. At the time of making the proposal in mid 2003, the NZ dollar was sitting at around 62c US. During the course of the project the strong New Zealand economy has pushed the value of our dollar as high as 78c US. As our expenses are in NZ currency but we will bill in US dollars, this has significantly devalued the project for the offeror.

A complete breakdown of all parts and subcontracts is given below in Table 1 on the following page.

Category	Item	NZD	USD
Major capital items	Fuel cells and modifications		17,555.00
	Inverter	3,428.00	
	Reformers and travel		107,000.00
Container and interior fitout	Battery tray	113.63	
	Castors	74.71	
	Coating of equipment frame	253.13	
	Electrical wiring and hardware	2,322.84	
	Equipment rack and framing	1,182.38	
	Exterior signage	2,244.16	
	Extraction fan	1,143.00	
	Filters and baffles	258.75	
	Floodlights	616.78	
	Fuel cell and reformer duct exit cowls	157.50	
	Fuel cell and reformer ducting	958.95	
	Heat detector switches	44.00	
	Linoleum flooring	455.63	
	Low voltage power supplies	113.00	
	Misc hardware	365.07	
	Pressure differential switch	63.00	
	Safety signage	323.28	
	Sealed lead acid batteries	939.60	
	Shipping container	3,813.75	
	Steel	404.74	
Site installation costs	Concrete drilling for cable ducts	80.00	
	Container transport	105.47	
	Electrical wiring and hardware	2,000.00	
	Hydrogen gas bottle cage	640.00	
	Scissor lift hire	110.50	
	Misc hardware	200.00	
Fuel infrastructure	Bunded methanol tank and stand	2,241.00	
	Gas fittings	775.28	
	Hydrogen manifold and installation	4,655.88	
	Methanol piping and tank installation	4,359.88	
	Pressure transducers	650.00	
	Trailer for methanol transport	2,075.00	
	Valves and controllers	2,105.02	
Consultants - professional services	Safety consultancy	630.00	
	Technology procurement consulting	10,000.00	
	Ventilation system design	1,350.00	
Data logging	Cellular modem and antenna	793.96	
	Current transducers	243.23	
	Custom electronics hardware	2,094.05	
	Monitoring computer	351.00	
	Sensor repeater barriers	1,233.06	
	Totals	**NZ$55,969.23**	**US$124,555.00**

Table 1 - Parts cost breakdown

Labour hours spent on the project by Industrial Research Ltd staff is broken down in Table 2

Category	**Project manager**	**Engineers**	**Technicians**	**Totals**
Administration, publicity and site liasion	100			**100**
Internal administration	57			**57**
Safety analysis		54		**54**
System specification and design	117	27		**144**
CAD layouts		37		**37**
Data logging system		105		**105**
Container fitout			185	**185**
Site installation			50.5	**50.5**
Commissioning and acceptance tests	103	71		**174**
Total:	**377**	**294**	**235.5**	**906.5**

Table 2 – Labour hours breakdown breakdown

15.0 Acceptance Test

The system was tested in several stages as equipment arrived and was installed in the container at the IRL workshop, so there was no final major commissioning test.

First test was of the fuel cells only, running from the bottled gas supply. Each fuel cell was run up to its rating individually using the grid connected inverter as a load, then both units at once. Total fuel cell power delivered exceeded 2000W, so the fuel cells are capable of running at their rated capacity.

Next the fuel cells were run with startup and shutdown via our automated system controller and data logger to check controller functions.

Upon arrival of the reformers, the Genesis engineers slotted the units into place in their frame and tested them manually. Once satisfied that there had been no transit damage and all functions were OK, they product gas was routed to the fuel cells, which were again tested up to rating on the reformer gas.

Final integration involved testing full system control with all components installed. We then individually tested shutdowns and failure sequences on each component to check stability of other components, particularly the ability of both reformers and the bottle gas pressure controller to cope with step loading changes if one reformer fails or there is an electrical load step on the fuel cell output.

The containerized unit was transported to the site and plumbed and wired into the building electrical system. Leak tests, system integrity and electrical safety tests were done by the relevant certified contractors or in-house technicians as equipment was installed. All critical safety systems – hydrogen sensors, pressure differential switches, heat detectors and emergency shut-off buttons were exercised and calibrated.

As a final check, a Hazardous Areas – Electrical inspector was engaged to inspect the unit for safety and sign off our Electrical Certificate of Compliance.

The system was formally inspected and accepted on behalf of CERL-ERDC by Dr Michael Binder, then the Program Manager, at the Acceptance Meeting on 18 May 2005.

Appendix

Monthy performance reports for April and May as submitted previously are also supplied with this document.